National Aeronautics and Space Administration

Advanced Exploration Systems

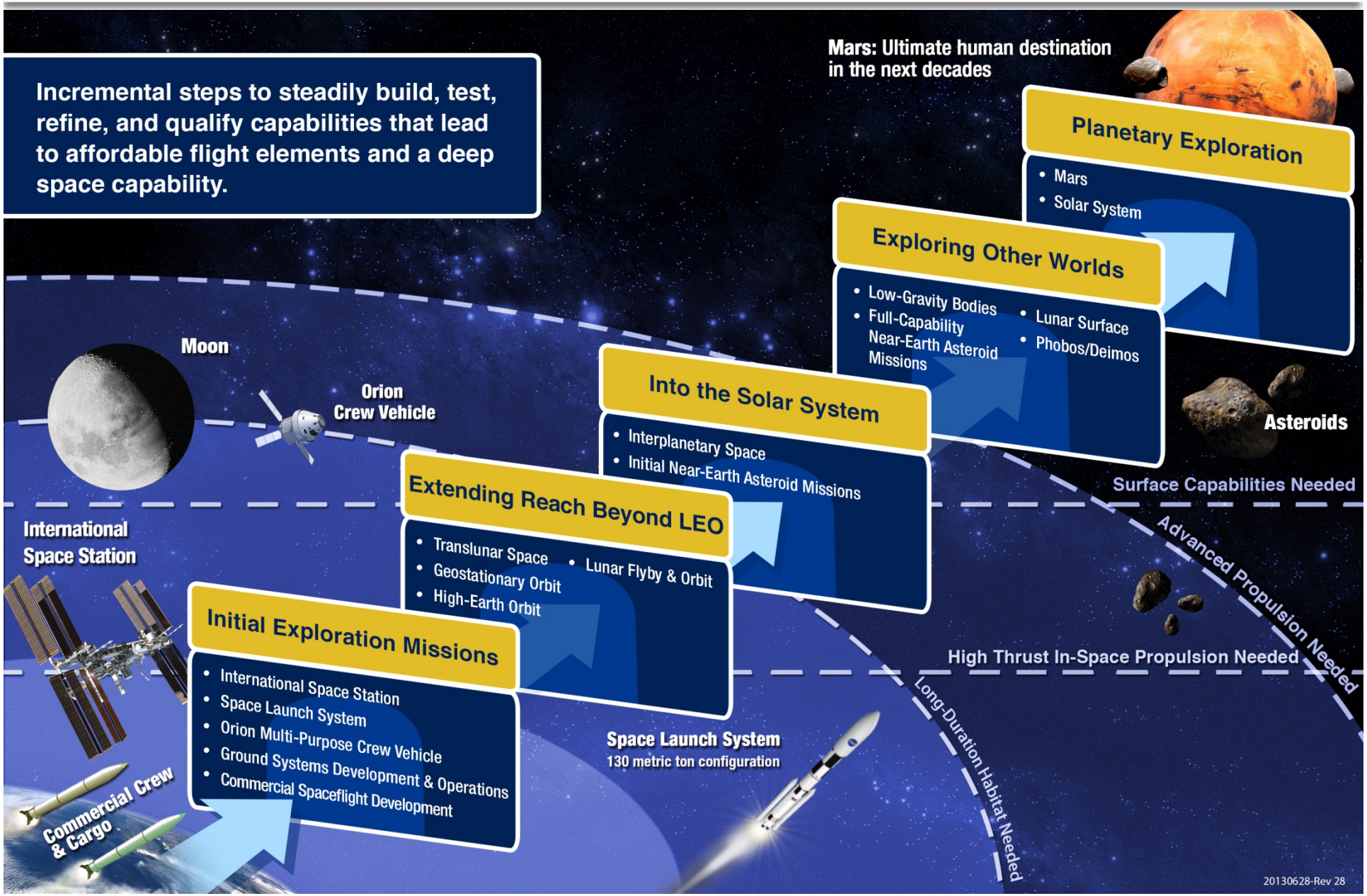
NASA Advisory Council • Exploration Committee
December 10, 2013

Jason Crusan, Director, Advanced Exploration Systems
Human Exploration and Operations Mission Directorate • NASA Headquarters

Topics

- HEOMD Investment Prioritization Process
- Advanced Exploration Systems Overview
- FY13 Milestone Outcomes
- Current FY14 Plans
- Industry-Led Robotic Lunar Lander

Capability Driven Framework

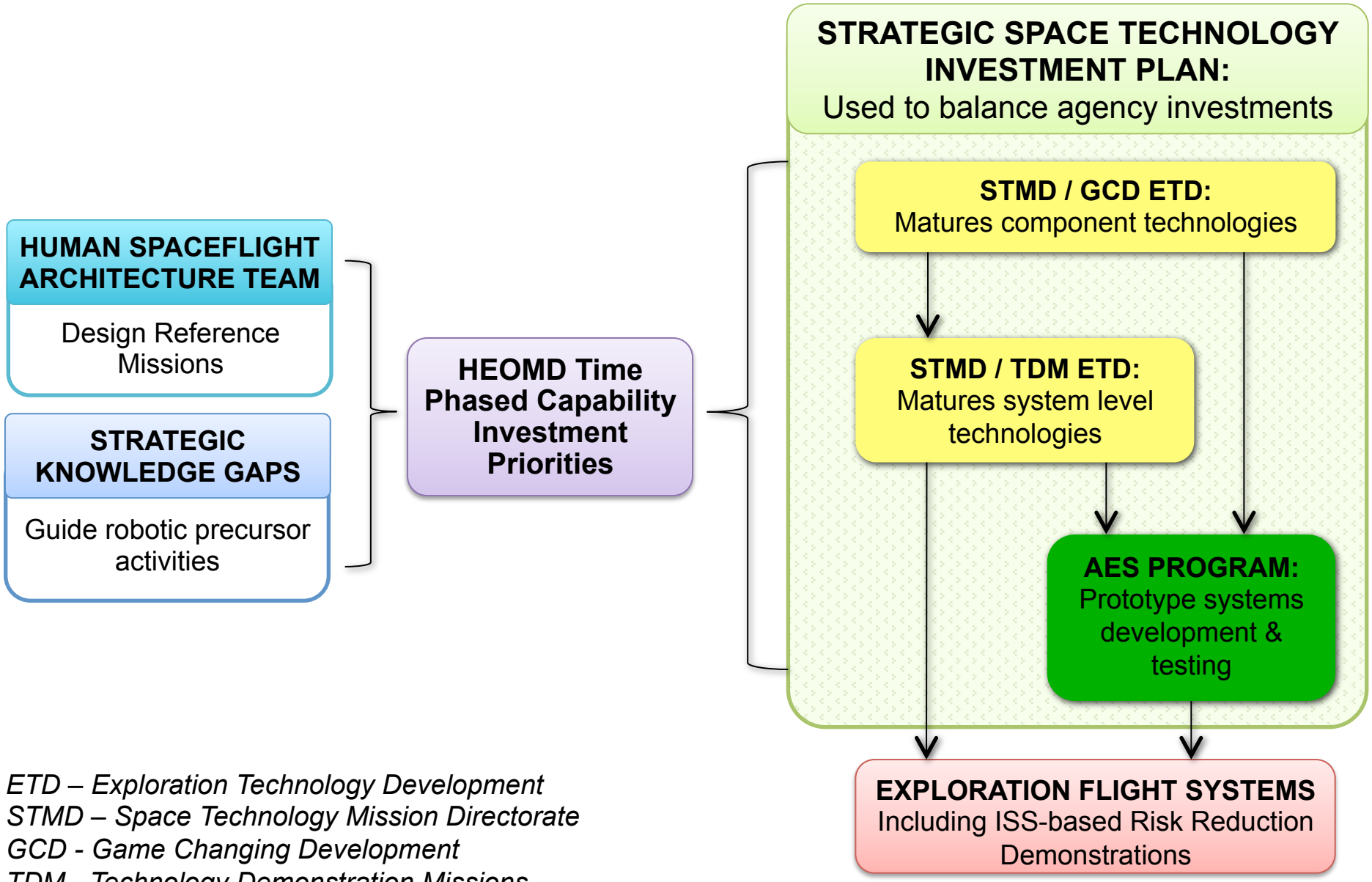


Principles for Incrementally Building Capabilities

Six key strategic principles to provide a sustainable program:

1. Executable with current *budget with modest increases*
2. Application of *high Technology Readiness Level* (TRL) technologies for near term, while focusing research on technologies to address challenges of future missions
3. *Near-term mission* opportunities with a defined cadence of compelling missions providing for an incremental buildup of capabilities for more complex missions over time
4. Opportunities for *US commercial business* to further enhance the experience and business base learned from the ISS logistics and crew market
5. *Multi-use* space infrastructure
6. Significant *international and commercial participation*, leveraging current International Space Station partnerships and commercial companies

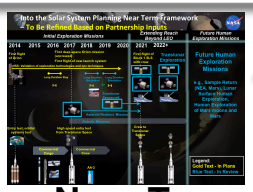
Old Version – Prioritization Process



ETD – Exploration Technology Development
STMD – Space Technology Mission Directorate
GCD - Game Changing Development
TDM - Technology Demonstration Missions

HEO Time Phased Capability Prioritization

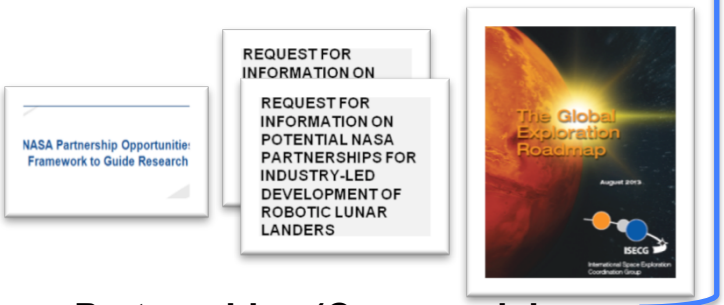
Mission Classes and Design Reference Missions



Near Term Strategy

HEO MD Objectives and Strategic Knowledge Gaps

Capabilities



Partnerships (Commercial, International via GER)

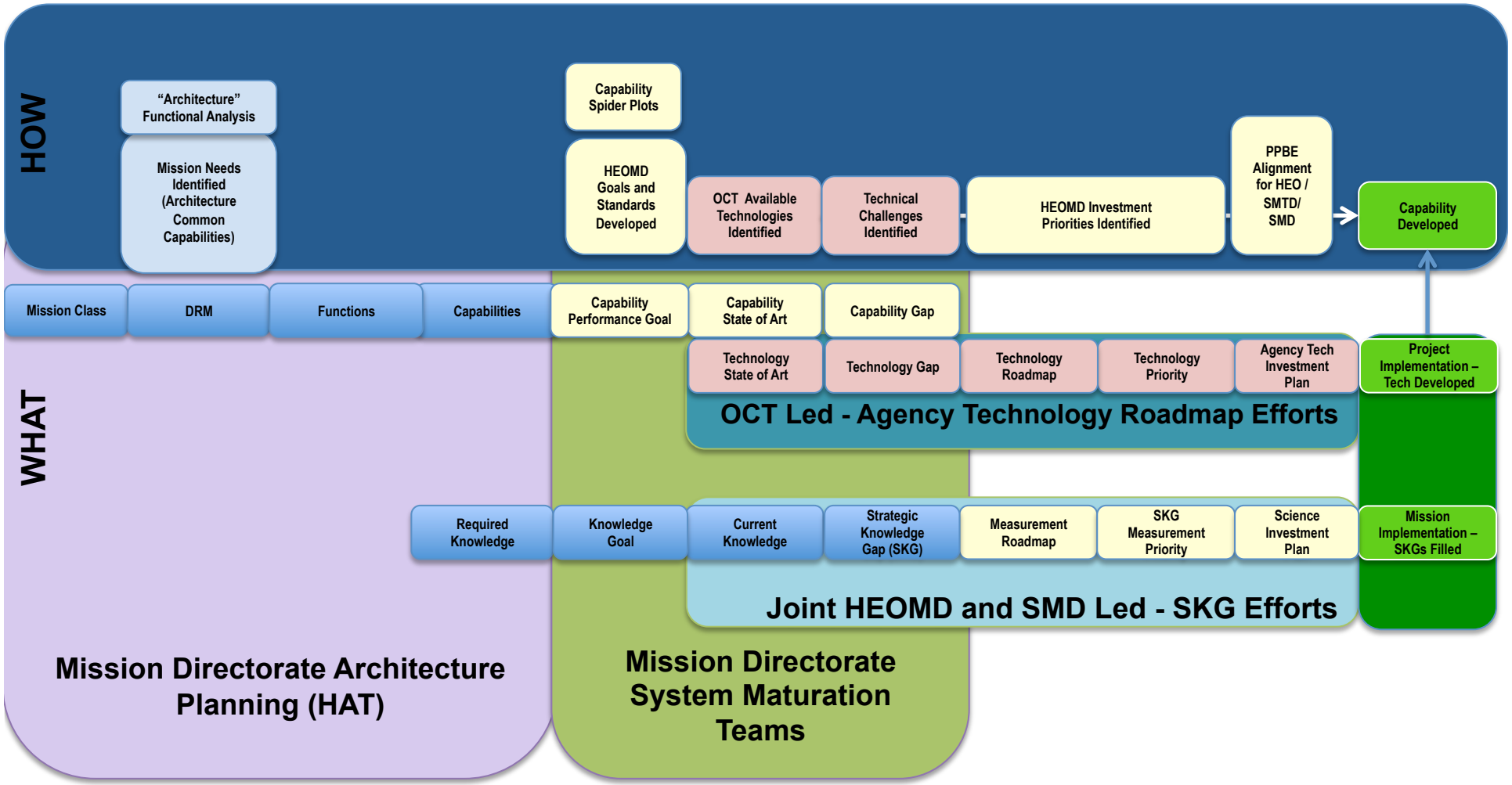
Information Captured for Sensitivity Analysis

Investment Priorities to HEOMD Divisions and Programs

Allows:

- Sensitivity analysis on objective satisfaction (asteroid mission, ISS testing, etc.)
- Make / buy / partner options
- Strategic considerations
- Portfolio recommendation
- Data required PPBE for programmatic decision / implementation processes

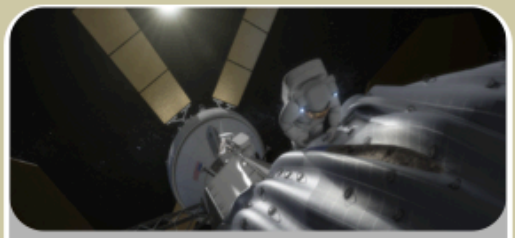
NASA Technology Roadmaps link to HEOMD Capability Driven Framework



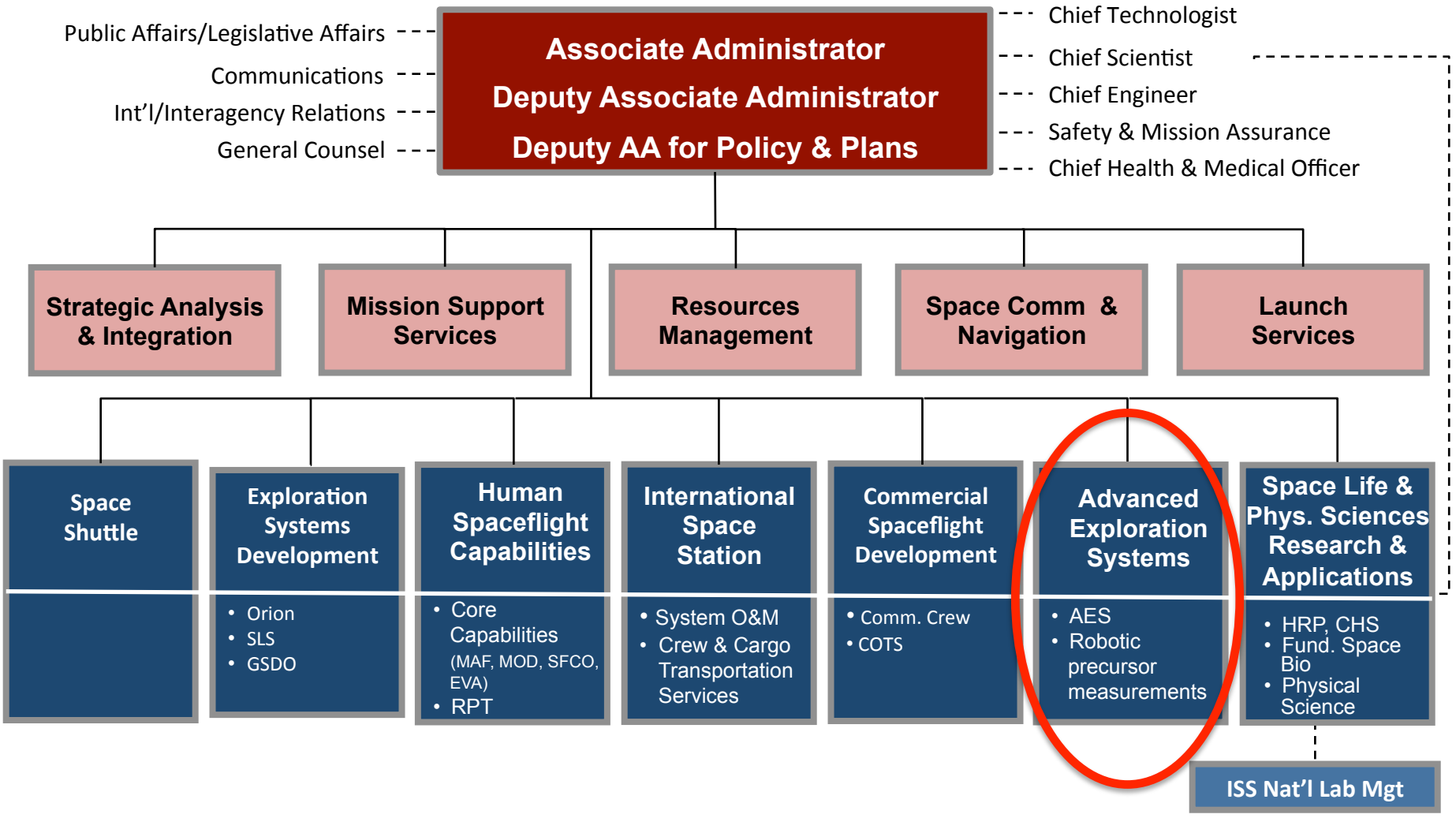
LEGEND

- In Progress HEOMD
- Completed
- To be updated starting FY '14
- Implementation Phase

Evolutionary Capabilities for Mars

	INTERNATIONAL SPACE STATION	ASTEROID REDIRECT MISSION & EXTENSIBILITY	HUMAN TO MARS
			
	ABORT MODE: HOURS Supply Chain: Robust	ABORT MODE: DAYS Supply Chain: Variable	ABORT MODE: MONTHS Supply Chain: Negligible
Environmental Life Support	◔ Long-Duration ◐ High-Reliability ◔ Deep-Space Environment ◐ Sustainable Commodities	◐ Long-Duration ◔ High-Reliability ◔ Deep-Space Environment ◔ Sustainable Commodities	● Long-Duration ● High-Reliability ● Deep-Space Environment ● Sustainable Commodities
Orbital Dynamics	● Vehicle Assembly ○ Long-Term Stable Orbits ○ 3-body Orbital Dynamics	◐ Vehicle Assembly ◔ Long-Term Stable Orbits ◐ 3-body Orbital Dynamics	● Vehicle Assembly ● Long-Term Stable Orbits ● 3-body Orbital Dynamics
Deep-Space Operations	◐ Long-Duration Autonomous Ops ◔ Deep-Space EVA ○ Sample Handling ○ ISRU	◔ Long-Duration Autonomous Ops ◐ Deep-Space EVA ◔ Sample Handling ◔ ISRU – In-Space Commodities	● Long-Duration Autonomous Ops ● Deep-Space and Surface EVA ● Sample Handling ● ISRU – Surface Commodities
MARS READINESS	◔ PARTIAL	◐ MODERATE	● COMPLETE

Human Exploration & Operations Mission Directorate
Organizational Structure



Background

In FY12, Exploration Technology Development (ETD) was transferred from HEOMD to Space Technology Program (Now STMD).

- ETD work was incorporated into two STMD Programs:
  - Game Changing Development (GCD) and
  - Technology Demonstration Missions (TDM)

- System-level integration work and prototype / design development for future exploration architecture elements remained in the HEOMD Advanced Exploration Systems (AES) Division.

ETD and AES Objectives

Exploration Technology Development (STMD)

- Develop long-range foundational technologies and components to support human exploration needs.
- Conduct flight demonstration missions of high-priority exploration capabilities such as cryogenic propellant storage and solar electric propulsion.
- Mature technologies for infusion into mission-level programs and agency initiatives.
- Leverage synergies with game-changing and crosscutting technologies to support multiple customers and mission applications.

Advanced Exploration Systems (HEOMD)

- Advanced development of exploration systems to reduce risk, lower lifecycle cost, and validate operational concepts for future human missions beyond Earth orbit.
- Demonstrate prototype systems in ground test beds, field tests, underwater tests, and International Space Station flight experiments.
- Use and pioneer innovative approaches for affordable rapid systems development and provide hands-on experience for the NASA workforce.
- Maintain critical competencies at the NASA Centers and provide NASA personnel with opportunities to learn new and transform skills.
- Infuse new technologies developed by Space Technology Mission Directorate / Exploration Technology Development into exploration missions.
- Support robotic missions of opportunity to characterize potential destinations for human exploration.

Advanced Exploration Systems

Rapid development and testing of prototype systems and validation of operational concepts to reduce risk and cost of future exploration missions:

- **Crew Mobility Systems**
  - Systems to enable the crew to conduct "hands-on" surface exploration and in-space operations, including crew excursion vehicles, advanced space suits, and crew egress
- **Deep Space Habitation Systems**
  - Systems to enable the crew to live and work safely in deep space, including deep space habitats, reliable life support, radiation protection, and fire safety
- **Vehicle Systems**
  - Systems for in-space propulsion stages and small robotic landers, including nuclear propulsion, modular power systems, lander technology test beds, and autonomous precision landing
- **Operations**
  - Systems to enable more efficient mission and ground operations, including integrated testing, autonomous mission ops, integrated ground ops, and logistics reduction
- **Robotic Precursor Activities**
  - Acquire strategic knowledge on potential destinations for human exploration to inform systems development, including prospecting for lunar ice, characterizing the Mars surface radiation environment, radar imaging of NEAs, instrument development, and research and analysis

Summary for FY13

•AES has established 64 project milestones for FY13. Goal was to achieve at least 80%..
•AES is developing over 14 flight experiments
•AES included 578 civil servants in FY13.

Collaboration with STMD

Active

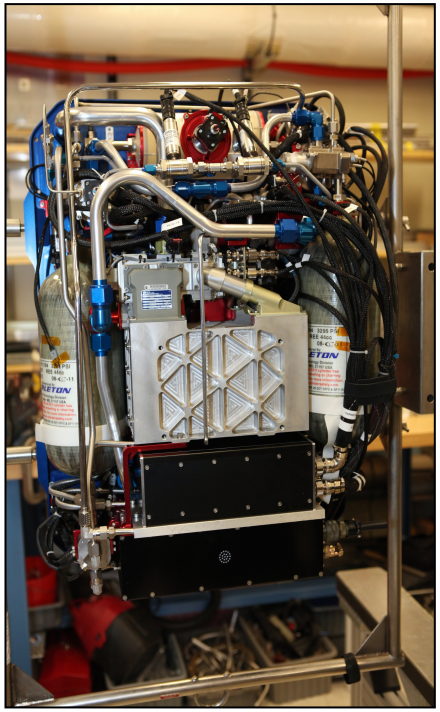
- EVA Portable Life Support System
- Advanced Life Support
- Radiation Protection
- Modular Power Systems
- Autonomous Systems for propellant loading
- Additive Manufacturing Demo on ISS
- Delay Tolerant Networking for Telerobotics on ISS
- Instruments for Resource Prospecting Mission

Formulation

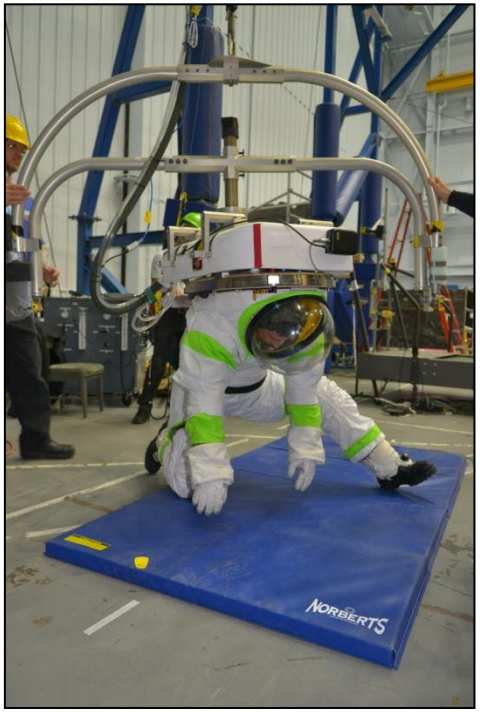
- Mars 2020 atmospheric ISRU demonstration
- Composite structures for SLS upper stage
- Asteroid Redirect Mission

FY13 Accomplishments

Crew Mobility Systems Domain



EVA: Completed assembly of the Portable Life Support System (PLSS) 2.0. This is the first new PLSS to be developed since the Shuttle EMU was introduced in 1981. The PLSS 2.0 incorporates new technology components developed by GCD/ STMD for CO2 removal, suit pressure regulation, thermal control, and energy storage.

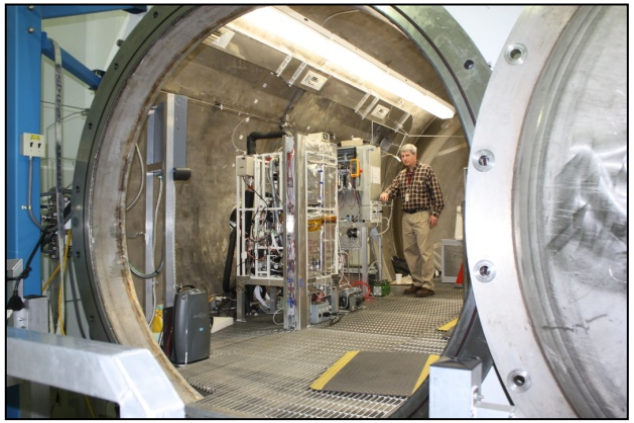


EVA: Assessed mobility of Z-1 suit with ARGOS gravity off-load system. Awarded Z-2 suit contract.

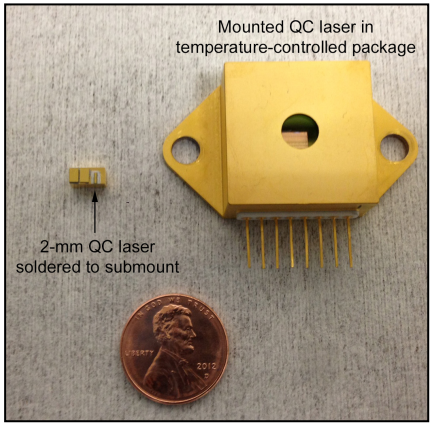
Habitable Airlock: Fabricated and assembled composite crew cabin for Habitable Airlock.

FY13 Accomplishments

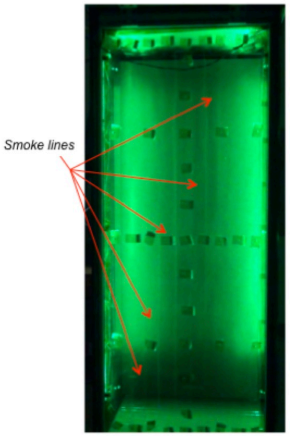
Deep Space Habitation Systems Domain



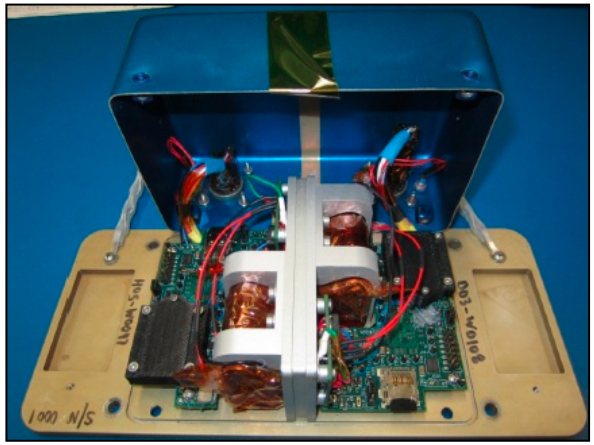
Life Support: Completed integrated chamber tests of ISS-derived Carbon Dioxide Removal Assembly, Trace Contaminant Control System, Sabatier reactor, and Oxygen Generation Assembly



Life Support: Fabricated quantum cascade laser with 4.75 μm wavelength for carbon monoxide detection.



Spacecraft Fire Safety: Large Scale fire propagation experiments – Conducted on ISS Cargo vehicle (Cygnus)

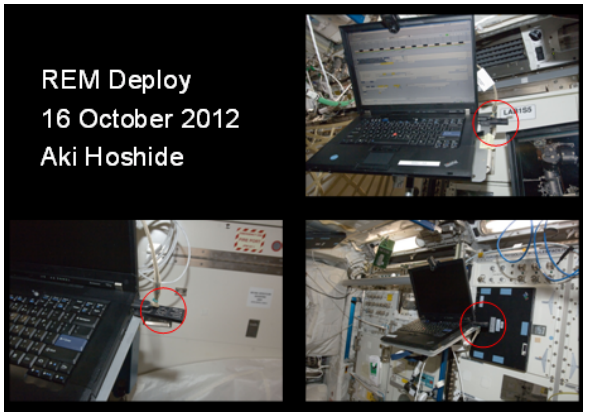


Radiation Protection: Completed CDR and delivered flight hardware for EFT-1 radiation environment monitors.

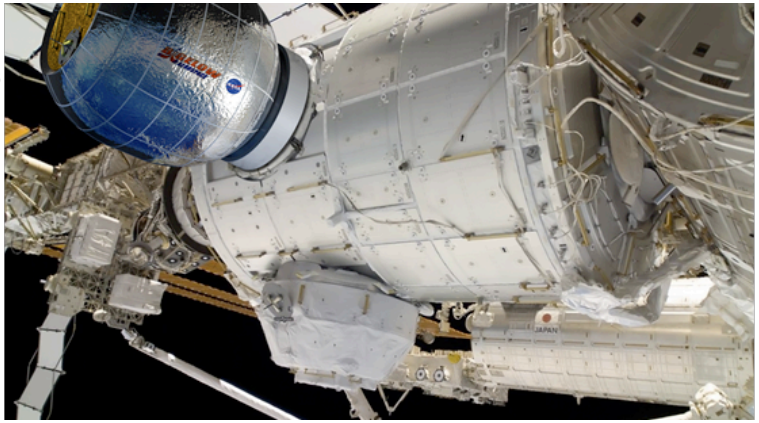
FY13 Accomplishments

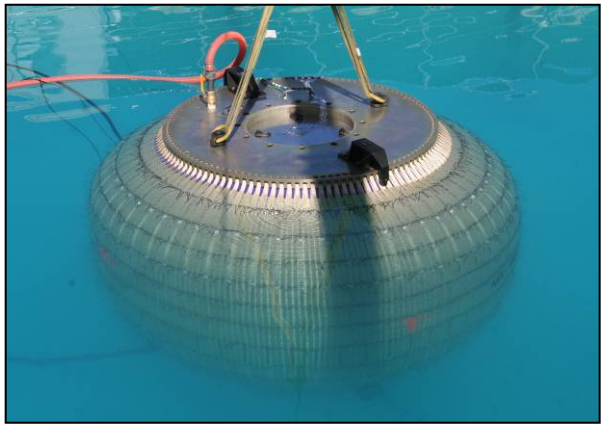
Deep Space Habitation Systems Domain

Habitat Systems: Refurbishing MPLM mockup for integration of crew accommodations, life support, power, and avionics.



Radiation Protection: Launched 5 radiation monitors to ISS and collecting data

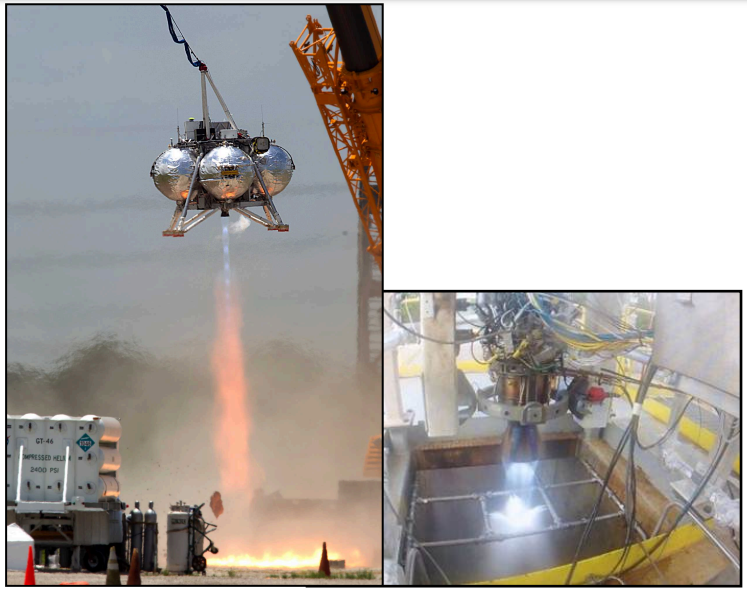




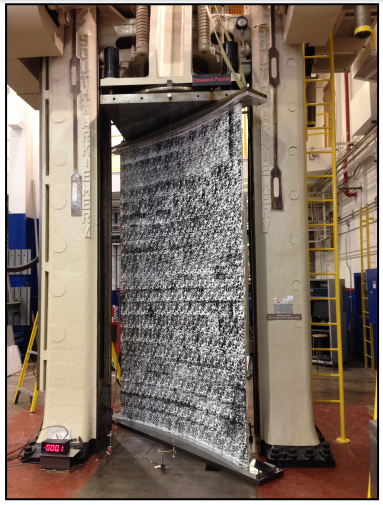
BEAM: Signed contract with Bigelow Aerospace to develop inflatable module for demonstration on ISS in 2015. Completed burst test to 8x operating pressure. Complete Phase 1 and 2 Safety Review Panels for ISS.

FY13 Accomplishments

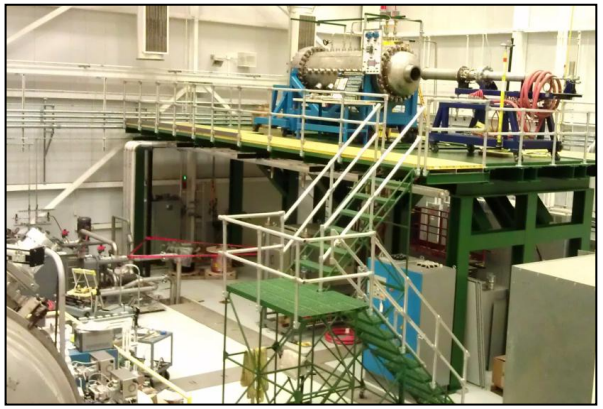
Vehicle Systems Domain



Morpheus: Completed assembly of new 1.5B vehicle with HD4 engine and resumed flight testing.

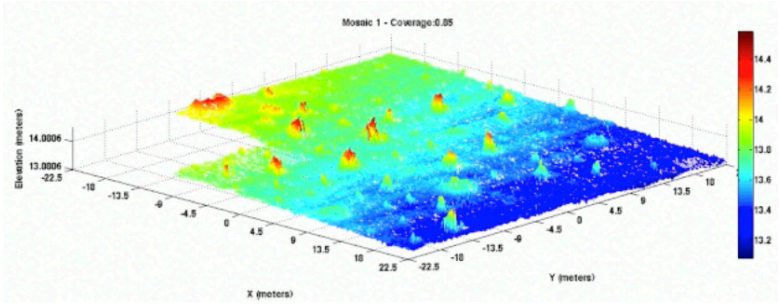


Composites: Tested 8 ft by 12 ft composite panel for SLS payload fairing to 33,000 lbf compressive load.



Nuclear Thermal Propulsion: Upgrading NTRESS test facility for operation at 1.5MW for fuel element testing

ALHAT: Advancing precision landing capabilities Recently completed helicopter flight tests of integrated ALHAT system at KSC to demonstrate hazard detection and safe landing site selection.



ALHAT: Digital elevation model of hazard field acquired by flash lidar

FY13 Accomplishments

Operations Domain

Ka-Band Objects Observation & Monitoring (KaBOOM): Next Generation system for Radar for NEA characterization. Completed installation of three 12 m antenna dishes at KSC and began bringing dishes operational.

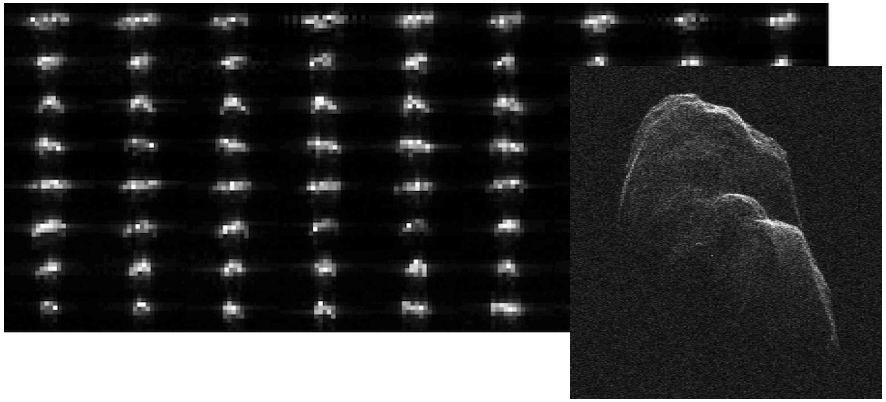
Integrated Ground Ops: Installed a 33,000-gallon LH2 tank (left) and 2,000-gallon LOX tank (right) at KSC to demonstrate zero boil-off cryogenic propellant storage, and autonomous control of propellant loading.

Operations Domain

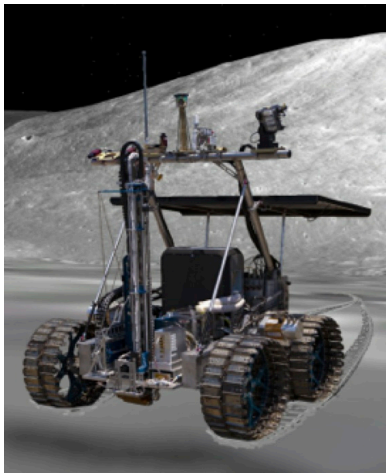
Disruption Tolerance Network: Demonstration next generation networking protocol. Used DTN protocols to control ESA robot on ground from ISS, and to teleoperate SPHERES free flyers on ISS from the Mission Control Center. A smartphone attached to SPHERES was used for wireless communications. DTN is supporting the STMD Human Exploration Telerobotics project.

FY13 Accomplishments

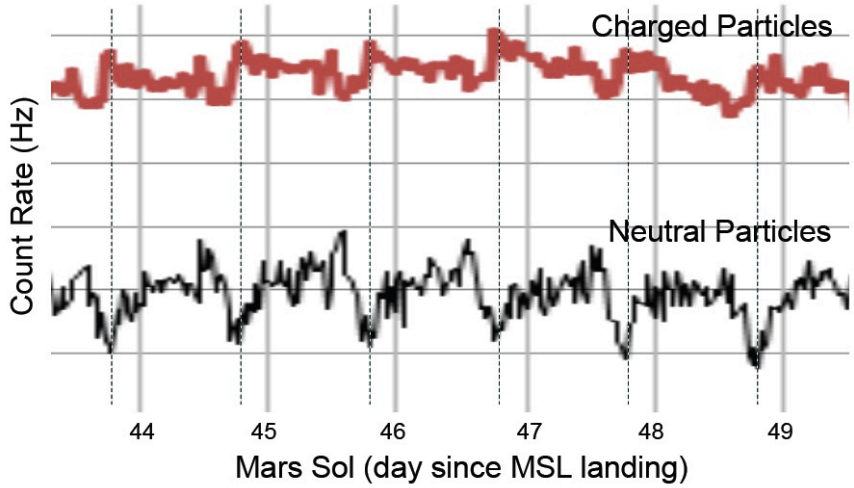
Robotic Precursor Activities Domain



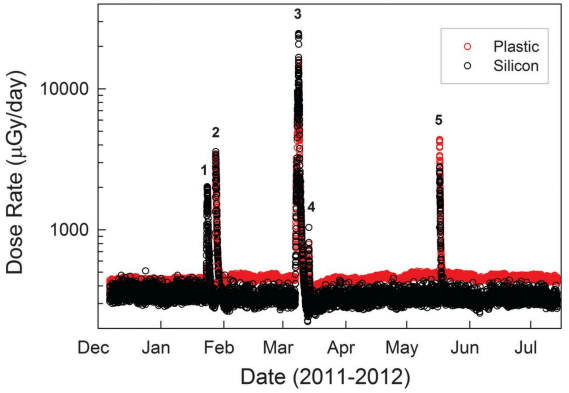
Goldstone Radar: Imaged 17 NEAs including 7 human accessible targets . Installed digital receiver at Arecibo to enable 4-meter resolution



Resource Prospector Mission: Completed Mission Concept Review.



Radiation Assessment Detector (RAD): Operating for 230+ sols on Mars. Discovered that neutron flux is anti-correlated with charged particle flux.



RAD: Published paper in *Science* on dose rate data acquired during cruise to Mars.

FY13 Milestone Status

All Milestones completed for FY13
Expect to complete in first quarter of FY14
Delayed beyond first quarter of FY14
Reduced budget related impacts

Project	Status
Autonomous Mission Ops	2 of 3 ISS demonstrations delayed.
Spacecraft Fire Safety	Completed MCR. Flight unit 1 subsystem assemblies delayed.
Modular Power Systems	Delivered DSH power distribution unit; DSH battery delayed.
Goldstone Radar	Imaged 17 NEOs, including 9 human accessible targets
Radiation Assessment Detector	Published SCIENCE paper on cruise results. Energy spectra analysis not complete.
Morpheus/ALHAT	ALHAT flight tests slipped due to delays in vehicle testing.
Integrated Testing	Deferred simulation of cis-lunar conops due to budget reduction.
Habitable Airlock	Tested breadboard pressure control system.
Deep Space Hab	Integrated systems with MPLM-based mockup and DSH test bed.
EVA	Completed PLSS 2.0 assembly. Vacuum chamber testing delayed.
Water Recovery	Thermal heat pump fabrication delayed.
Air Resource Recovery & Env. Monitoring	Cycle 2 testing delayed due to budget reduction
Radiation Protection	Completed assembly of radiation monitors for EFT-1

Project	Status
Logistics Reduction	Gen 2 Heat Melt Compactor fab delayed due to budget reduction
Integrated Ground Ops	LH2 propellant loading demo delayed due to budget reduction
Resource Prospector Mission	Completed MCR. Seeking partner to develop lander
Nuclear CPS	Graphite composite fuel element fab delayed due to budget reduction
SSERVI (NLSI)	Issued CAN to select new teams. Awards delayed due to FY14 budget.
Lunar Mapping & Modeling	Completed 3D viewing tools; supporting RPM.
BEAM	Completed burst pressure test. PDR of Dragon FSE delayed.
Core Flight Software	Implementing CFS on fault tolerant computing architectures
Avionics Architectures	Completed integrated tests of reference avionics architecture
Delay Tolerant Networking	Infusion into DSH delayed
KaBOOM	Adaptive atmospheric correction demo delayed.
Additive Manufacturing	Developing 3D printer for ISS demo. Completed CDR.
Composites	Tested large composite panels
OPALS	Delivered hardware to KSC for launch

46 of 64 milestones (72%) or 52 of 64 milestones (81%), excluding budget related impacts.

Program Changes in FY14

- **New Exploration Augmentation Module effort will consolidate several existing projects to focus on development of a prototype module to augment Orion's habitation and EVA capabilities for extended deep space missions. The following projects will not be continued:**
  - Deep Space Habitat
  - Habitable Airlock (MMSEV)
  - Integrated Testing

- **EVA project will develop modified Advanced Crew Escape Suit (M-ACES) for potential use on early Orion missions and also the Asteroid Redirect Mission.**

- **AES plans to develop Industry-led lunar lander partnerships. Released an RFI earlier this year that had significant responses which are being use to craft forward plan.**

- **New project to demonstrate oxygen production from Martian atmosphere on Mars 2020 mission:**
  - In-situ propellant production is an architecture enabling technology for future human missions.
  - Payload will include atmospheric dust size and surface weather measurements to address high priority SKGs.
  - Payload is being competed via SMD Mars 2020 AO, and will be co-funded by AES and STMD.

- **Selected three new projects to develop CubeSat secondary payload concepts for launch on EM-1:**
  - Biosentinel
  - NEA Scout
  - Lunar Flashlight

Major FY14 AES Milestones

Feb 2014	**Exploration Augmentation Module:** Functional and Performance Requirements developed and required systems/ subsystems identified
Apr 2014	**Resource Prospector Mission**: Determine partner approach(International or domestic) for development of robotic lunar lander.
Apr 2014	**Morpheus/ALHAT**: Complete KSC flight tests of ALHAT on Morpheus lander to demonstrate autonomous hazard detection and avoidance.
May 2014	**Mars 2020**: Select payload to demonstrate oxygen production from Mars atmosphere.
Jun 2014	**Additive Manufacturing**: Deliver 3D printer for launch to ISS.
Jul 2014	**Spacecraft Fire Safety**: Complete manufacturing and assembly of flight unit #1.
Jul 2014	**EVA**: Conduct human-in-the-loop testing with PLSS 2.0.
Sep 2014	**Radiation Protection**: Launch radiation environment monitors on EFT-1.
Sep 2014	**Autonomous Mission Ops**: Demonstrate advanced caution and warning system on EFT-1.

AES Highlight - CubeSat Launch Initiative - ELaNa Missions

National Aeronautics and Space Administration

CubeSat ELaNa IV Launch on ORS-3
November 2013

OVERVIEW

NASA will launch eleven small research satellites, or CubeSats, for nine universities, one high school and one NASA Center as part of the fourth installment of the Educational Launch of Nanosatellite (ELaNa) mission. Over 300 students have been involved in building the CubeSats that will be flown as auxiliary payloads on the U.S. Air Force-led Operationally Responsive Space-3 (ORS-3) launch planned for November 2013.

The ELaNa CubeSat Launch Initiative enables students, teachers and faculty to obtain hands-on flight hardware development experience and gives them access to a low-cost vehicle to conduct research in the areas of science, exploration, technology development, education or operations. Since its inception in 2010, the initiative has selected more than 90 CubeSats from primarily educational and government institutions around the U.S. These miniature satellites were chosen from a prioritized queue established through a shortlisting process from proposers that responded to public announcements on NASA's CubeSat Launch Initiative. NASA will announce another call for proposals in mid-August 2014.

Ho`oponopono-2 (H-2)

University of Hawaii – Honolulu

Ho`oponopono-2 (Hawaiian for "to make right") will provide a student-built, low-cost radar calibration nanosatellite carrying a C-band transponder and high-accuracy GPS payload to continue a long-existing radar calibration and performance service supplementing two existing, aging spacecraft.

Basic CubeSat Facts:

- Built to standard dimensions of 1 unit (1U) which is equal to 10x10x10 cm
- Can be 1U, 2U, 3U or 6U in size
- Weigh less than 1[1/3] kg (3 lbs) per U – 6U may be up to 12-14 kg
- Deployed from standard Poly-Picosatellite Orbital Deployer (P-POD)

CUBESAT DEPLOYMENT

Eleven CubeSat projects were selected for the ELaNa IV mission. There will be eight Poly Picosatellite Orbital Deployers (P-PODs) aboard the Minotaur-1 rocket that will ferry them to space. The P-POD was designed and manufactured by the California Polytechnic State University (Cal Poly) of San Luis Obispo, Calif., to integrate CubeSats onto launch vehicles. After the main payload deploys, the CubeSats will separate from their P-PODs. After 45 minutes in orbit, the CubeSat transmitters will turn on and university ground stations will listen for their beacons, determine their small satellites' functionality and announce operational status. CubeSat mission durations and orbital life vary, but are anticipated to last at least 180 days. Upon mission completion, the CubeSats fall to Earth, burning up in the atmosphere.

SAFETY AND MISSION ASSURANCE

Each CubeSat developer verified that its satellite complied with the P-POD requirements. NASA jointly conducted a mission readiness review with each CubeSat developer.

NASAfacts

National Aeronautics and Space Administration

ELaNa II CubeSat Launch on NROL-39 Mission
December 2013

OVERVIEW

NASA will launch four small research satellites, or CubeSats, for three universities and NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif., as part of the fifth installment of the Educational Launch of Nanosatellite (ELaNa) mission. Over 100 students have been involved in building the CubeSats that will be flown as auxiliary payloads on the National Reconnaissance Office's launch of its NROL-39 mission planned for December 2013.

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CUBESAT DEPLOYMENT

Four CubeSat projects were selected for the ELaNa II mission. There will be two Poly Picosatellite Orbital Deployers (P-PODs) aboard the Atlas V rocket that will ferry them to space. The P-POD was designed and manufactured by the California Polytechnic State University (Cal Poly) of San Luis Obispo, Calif., to integrate CubeSats onto launch vehicles. After the main payload deploys, the CubeSats will separate from their P-PODs. After 45 minutes in orbit, the CubeSat transmitters will turn on and university ground stations will listen for their beacons, determine their small satellites' functionality and announce operational status. CubeSat mission durations and orbital life vary, but are anticipated to last at least 180 days. Upon mission completion, the CubeSats fall to Earth, burning up in the atmosphere.

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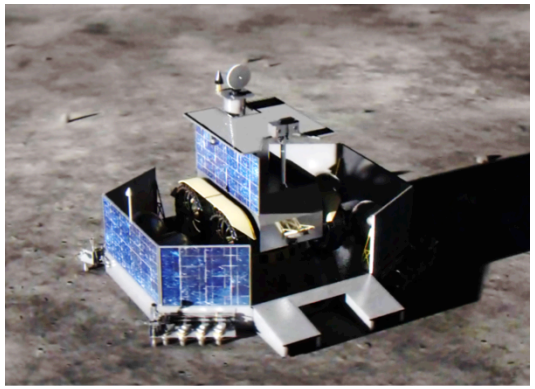
NASAfacts

AES Highlight - Industry Robotic Lander Partnership

NASA is seeking external partnerships for joint development of a robotic lunar landing capability as early as 2018



- **Applicable to a variety of precursor exploration and science missions to lunar surface**
  - **Medium class (250-450 kg payload): e.g. Resource prospecting, Sample return**
  - **Small class (30-100 kg): e.g. Geophysical network deployment**
- **Potential NASA contributions to a partnership:**
  - **Technical Expertise, Test Facilities, Hardware and Software**
  - **No exchange of funds envisioned between NASA and Partner(s)**
- **Commercial Partnership**
  - **Stimulate commercial capability to deliver payloads to the lunar surface**
  - **NASA RFI to assess interest and feasibility of public-private partnerships with U.S. industry**
  - **Received a robust response**
  - **Final partnership mechanism type to be determined, e.g., Space Act Agreement (SAA), Cooperative Research and Development Agreement (CRADA)**


NASA
Tournament Lab


FREE FLIGHT
NO STRINGS ATTACHED
MORPHEUS